

Sedentary behaviour and risk of mortality from all-causes and cardiometabolic diseases in adults: evidence from the HUNT3 population cohort

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ABSTRACT

Background Sedentary behaviour is a potential risk factor for chronic-ill health and mortality, that is, independent of health-enhancing physical activity. Few studies have investigated the risk of mortality associated with multiple contexts of sedentary behaviour.

Objective To examine the prospective associations of total sitting time, TV-viewing time and occupational sitting with mortality from all causes and cardiometabolic diseases.

Methods Data from 50 817 adults aged ≥ 20 years from the Nord-Trøndelag Health Study 3 (HUNT3) in 2006–2008 were linked to the Norwegian Cause of Death Registry up to 31 December 2010. Cox proportional hazards models examined all-cause and cardiometabolic disease-related mortality associated with total sitting time, TV-viewing and occupational sitting, adjusting for multiple potential confounders including physical activity.

Results After mean follow-up of 3.3 years (137 315.8 person-years), 1068 deaths were recorded of which 388 were related to cardiometabolic diseases. HRs for all-cause mortality associated with total sitting time were 1.12 (95% CI 0.89 to 1.42), 1.18 (95% CI 0.90 to 1.57) and 1.65 (95% CI 1.24 to 2.21) for total sitting time 4–<7, 7–<10 and ≥ 10 h/day, respectively, relative to <4 h/day after adjusting for confounders (p -trend=0.001). A similar pattern of associations was observed between total sitting time and mortality from cardiometabolic diseases, but TV-viewing time and occupational sitting showed no or borderline significant associations with all-cause or cardiometabolic disease-related mortality over the same follow-up period.

Conclusions Total sitting time is associated with all-cause and cardiometabolic disease-related mortality in the short term. However, prolonged sitting in specific contexts (ie, watching TV, at work) do not adversely impact health in the same timeframe. These findings suggest that adults should be encouraged to sit less throughout the day to reduce their daily total sitting time.

INTRODUCTION

Sedentary behaviour is gaining attention as an independent behavioural risk factor for chronic illness.¹ The term ‘sedentary behaviour’ is defined as any waking behaviour involving little or no energy expenditure (1–1.5 METs) while in a sitting or reclining posture² and includes sitting during transport, at work, in leisure time and at home. The literature suggests that even when adults are sufficiently active according to physical activity guidelines, higher levels of sedentary behaviour

may be independently associated with an increased risk of chronic diseases.^{3–4}

Few epidemiological studies have examined specific sedentary behaviours and health outcomes longitudinally. A systematic review of prospective studies published between 1989 and February 2010³ identified only 19 studies for inclusion, of which 14 were of high methodological quality. The authors concluded that there was a moderate evidence that higher amounts of sedentary behaviour was associated with an increased risk of type 2 diabetes, and that there was strong evidence of a relationship between sedentary behaviour and all-cause and cardiovascular disease (CVD)-related mortality. A later systematic review, which did not account for methodological quality, reached similar conclusions about the prospective association between sedentary behaviour and health outcomes.⁴

Evidence from prospective studies suggests that all-cause and/or CVD-related mortality is positively associated with specific sedentary behaviour contexts and domains, including TV-viewing,^{5–7} leisure screen-based activity,⁸ leisure-time sitting,⁹ sitting in main activities (during work, school and housework),¹⁰ riding in a car¹¹ and occupations involving ‘mostly sitting’.¹² Three prospective studies indicate that higher amounts of total time spent sitting is associated with greater risk of all-cause^{5 13 14} and CVD-related⁵ mortality and that associations between total sitting time and mortality are independent of the participants’ physical activity.^{5 13 14} When assessed objectively with accelerometers, higher sedentary time also appears to be associated with higher risk of mortality independent of moderate-to-vigorous physical activity.¹⁵

This study aimed to build on this evidence base with an analysis of the HUNT3 population cohort from Nord-Trøndelag county, Norway. The advantage of this large population cohort study is that the information was collected on adults’ total sitting time, and also on TV-viewing and occupational sitting time. The purpose of this study was to examine the prospective associations of total sitting time, TV-viewing time and occupational sitting with mortality from all causes and cardiometabolic diseases (CMD).

METHODS

Study population

The Nord-Trøndelag Health Study (HUNT) is a large prospective population-based cohort study of residents of Nord-Trøndelag county (central Norway). To date, there have been three waves of

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data collection: 1985–1987 (HUNT1), 1995–1997 (HUNT2) and 2006–2008 (HUNT3).^{16 17}

This paper focuses on the HUNT3 cohort; however, a sub-study was conducted involving HUNT2 participants. We present details of the HUNT3 study population and measures in brief below, and a description of the HUNT2 cohort has been provided elsewhere.^{16 17}

All Nord-Trøndelag county residents aged at least 20 years old were invited to participate in the HUNT3 survey with an invitation letter and questionnaire sent by post (n=94 194). Residents accepted the invitation by providing informed consent, completing the questionnaire and attending a clinic for a physical examination and additional questionnaire(s).^{16 17} HUNT3 had a response rate of 54% and 44% for the first and second questionnaires, respectively. Participants self-reported information on a range of health and lifestyle topics and demographic information (eg, education level, tobacco use, medical history and general health).

The HUNT2 and HUNT3 surveys and data access permissions for this study were approved by the Norwegian Data Inspectorate and the Regional Committee for Medical and Health Research Ethics (REC) in Mid Norway.

Sitting variables

HUNT3 participants reported their total sitting time as a continuous measure in response to the question 'About how many hours do you sit during an average day? (include work hours and leisure time)'. This is similar to the sitting measure from the frequently used International Physical Activity Questionnaire that has shown acceptable reliability and validity.^{18 19} Daily time spent watching TV, videos or DVD was assessed with the categories: <1, 1–3, 4–6, >6 h/day.

Participants rated their occupational sitting/activity using the following categories: 'work that mostly involves sitting'; 'work that requires much walking'; 'work that requires much walking and lifting'; and 'heavy physical labour'. This type of categorical occupational sitting/activity measure has been commonly used in other prospective cohort studies.¹²

The HUNT2 survey asked participants to indicate their occupational sitting/activity with the same question used in HUNT3, but it did not ask about total sitting time or daily TV-viewing, video or DVD time.

Other variables

The HUNT3 survey recorded information about participants' smoking (never smokers, ex-smokers or current smokers), participants' self-rated general health at the time of survey (poor, not so good, good and very good) and their history of chronic illness (eg, heart disease, diabetes, stroke and cancer). Participants indicated whether or not they met the Norwegian physical activity recommendations for adults: 'Do you have at least 30 min of physical activity daily at work or in your leisure time?' (yes/no).

Height and weight were objectively measured at the physical examination and body mass index (BMI) was calculated as weight/height² (kg/m²). Underweight was defined as BMI<18.5 kg/m², normal weight as BMI 18.5–24.9 kg/m², overweight as BMI 25–29.9 kg/m² and obese as ≥30 kg/m². Participants' sex and date of birth information were obtained via their National Personal Identification Numbers.

CMD status was defined as those that reported ever having been diagnosed with myocardial infarction, angina pectoris, stroke, other heart disease, heart failure and/or diabetes and/or hyperglycaemia. Participants without diagnosed CMD or cancer

were considered 'healthy' relative to those with CMD. For the purposes of this study, we refer to these two subgroups as participants with CMD and healthy participants. People with cancer were included in the total sample, but not in the 'healthy' group of the CMD classification.

Endpoints and follow-up

The endpoints of this study were mortality from all causes and from CMD. Deaths among HUNT2 and HUNT3 participants were identified through linkage to the Norwegian Causes of Death Registry using their unique Personal Identification Number, assigned to every Norwegian citizen at birth. We obtained death information for the period from 1 January 1994 to 31 December 2010. Each participant contributed person years from the date of the clinical examination until the date of death or until the end of follow-up, whichever came first. Causes of death were coded based on the International Classification of Disease (ICD). We identified deaths from CMD (diseases of the circulatory system, and endocrine, nutritional and metabolic diseases) using ICD-9 (codes 240–279, 390–459) for deaths occurring up to 1996 and ICD-10 (codes E10–E16, E65–E68, I00–I99) for deaths from 1996 onwards.

Statistical analyses

The relationship between the various measures of sitting (total, occupational, TV-viewing) and mortality was analysed using Cox proportional hazards models for both all-cause mortality and CMD mortality. Age was the time scale used with age at screening as the time of study entry and age at death/censoring as the exit time. Age, rather than time-on-study, was used as the time scale as previous simulation studies have shown that the former method yields more accurate results because risk estimates are calculated on people of the same age.²⁰ Total sitting time was divided into four categories <4, 4–<7, 7–<10 and ≥10 h/day based on the distribution of the data, with <4 h/day as the reference category. For analyses of TV/DVD viewing, the two categories watched 4–6 and >6 h/day were combined because of small cell sizes and watching <1 h/day was the reference category. Occupational sitting used 'Work that mostly involves sitting' as the reference category.

All models were adjusted for sex, educational level, BMI category, meeting physical activity guidelines (yes/no), smoking status and general health, whether the person reported CMD. To maximise the statistical power, participants with missing values for education and BMI were modelled as a separate missing category. The assumption for proportionality (for sitting categories) was tested using analytic and graphical means²¹ and was met by all models. All analyses were conducted with Stata V11.1 (StataCorp LP, College Station, Texas, USA, 2009) and used a 0.05 threshold for statistical significance.

The final sample for HUNT3 in the present analyses included 50 817 respondents who completed at least one study component (questionnaire and physical examination).

RESULTS

Of the 50 817 HUNT3 participants, 54.6% were women, 66.8% were overweight or obese, 76.1% met physical activity recommendations, 42.8% never smoked, 71.6% reported being in 'good' to 'very good' health, 32% reported sitting at least 7 h/day, 32.5% reported mostly sitting at work and 70.2% watched 1–3 h/day of television.

Table 1 presents the baseline participant characteristics for the HUNT3 sample by categories of total sitting time, TV-viewing time and occupational sitting. Total sitting time tended to be

Table 1 Baseline participant characteristics according to total sitting time, TV-viewing time and occupational sitting/activity categories, HUNT3

Demographic variables	Total sitting time categories (h/day)				TV-viewing categories (h/day)			Occupational sitting categories			
	4–<7 n (%)	7–<10 n (%)	≥10 n (%)	<1 n (%)	1–3 n (%)	≥4 h n (%)	Mostly sitting n (%)	Much walking n (%)	Much walk and lift n (%)	Heavy labour n (%)	
All	8828 (20.2)	20969 (47.9)	8171 (18.7)	5811 (13.3)	6640 (16.6)	28 114(70.2)	5309 (13.3)	11946 (32.5)	11624 (31.6)	9679 (26.3)	3568 (9.7)
Sex											
Female	4799 (21.0)	11340 (49.6)	4248 (18.6)	2458 (10.8)	3731 (16.6)	15784 (70.1)	3000 (13.3)	5688 (29.7)	7237 (37.8)	5799 (30.3)	441 (2.3)
Male	4029 (19.3)	9629 (46.0)	3923 (18.7)	3353 (16.0)	2909 (16.6)	12330 (70.3)	2309 (13.2)	6258 (35.5)	4387 (24.9)	3880 (22.0)	3127 (17.7)
Age (years)											
18–<45	3528 (23.2)	6544 (43.0)	3031 (19.9)	2105 (13.8)	2493 (21.5)	7960 (68.6)	1148 (9.9)	4548 (30.4)	4581 (30.6)	4510 (30.2)	1315 (8.8)
45–<60	2830 (18.9)	6870 (45.9)	2964 (19.8)	2292 (15.3)	2612 (19.7)	9348 (70.5)	1300 (9.8)	5197 (34.9)	4738 (31.8)	3714 (24.9)	1245 (8.4)
≥60	2444 (18.2)	7467 (55.6)	2147 (16.0)	1375 (10.2)	1532 (10.1)	10783 (71.1)	2858 (18.8)	2163 (31.6)	2265 (33.1)	1416 (20.7)	994 (14.5)
BMI (kg/m ²)											
<18.5	38 (14.7)	125 (48.5)	49 (19.0)	46 (17.8)	49 (20.7)	146 (61.6)	42 (17.7)	57 (31.0)	51 (27.7)	66 (35.9)	10 (5.4)
18.5–24.9	3163 (22.5)	6570 (46.6)	2643 (18.8)	1716 (12.2)	2558 (20.2)	8754 (69.0)	1376 (10.8)	3703 (30.1)	4322 (35.2)	3361 (27.4)	902 (7.3)
25–29.9	3906 (20.0)	9437 (48.4)	3630 (18.6)	2547 (13.1)	2819 (15.8)	12629 (70.9)	2367 (13.3)	5496 (33.6)	4874 (29.8)	4205 (25.7)	1788 (10.9)
≥30	1680 (17.5)	4725 (49.1)	1797 (18.7)	1413 (14.7)	1196 (13.0)	6500 (70.7)	1495 (16.3)	2621 (33.6)	2327 (29.8)	1998 (25.6)	853 (10.9)
Unknown	41 (14.0)	112 (38.1)	52 (17.7)	89 (30.3)	18 (13.6)	85 (64.4)	29 (22.0)	69 (37.7)	50 (27.3)	49 (26.8)	15 (8.2)
Education level*											
Basic upper secondary or less	3916 (21.0)	10025 (53.9)	2866 (15.4)	1803 (9.7)	2217 (11.7)	13405 (70.4)	3414 (17.9)	3321 (24.6)	4171 (30.9)	3940 (29.2)	2049 (15.2)
Advanced upper secondary	2797 (22.6)	5678 (46.0)	2271 (18.4)	1607 (13.0)	1740 (17.4)	7133 (71.5)	1106 (11.1)	3418 (29.1)	3453 (29.4)	3646 (31.0)	1243 (10.6)
Tertiary	2004 (16.3)	5052 (41.1)	2916 (23.7)	2333 (19.0)	2621 (24.7)	7293 (68.8)	691 (6.5)	5102 (45.4)	3893 (34.6)	2002 (17.8)	240 (2.1)
Unknown	111 (21.7)	214 (41.9)	118 (23.1)	68 (13.3)	62 (14.0)	283 (63.9)	98 (22.1)	105 (31.0)	107 (31.6)	91 (26.8)	36 (10.6)
Meet physical activity guidelines†											
No	1179 (11.6)	3774 (37.1)	2546 (25.1)	2663 (26.2)	1504 (15.8)	6461 (68.0)	1537 (16.2)	4969 (63.4)	1875 (23.9)	771 (9.8)	226 (2.9)
Yes	7646 (22.8)	17191 (51.2)	5621 (16.7)	3143 (9.4)	5129 (16.8)	21628 (70.9)	3766 (12.3)	6972 (24.1)	9748 (33.7)	8905 (30.8)	3339 (11.5)
Smoking status											
Never smoked	4040 (21.1)	8859 (46.4)	3712 (19.4)	2500 (13.1)	3444 (19.9)	12093 (69.9)	1769 (10.2)	5601 (33.9)	5252 (31.8)	4024 (24.4)	1630 (9.9)
Ex-smoker	2070 (17.7)	5777 (49.3)	2242 (19.1)	1631 (13.9)	1568 (14.2)	7870 (71.0)	1643 (14.8)	3170 (34.2)	2949 (31.8)	2332 (25.1)	830 (8.9)
Current smoker	2536 (20.6)	6018 (48.9)	2124 (17.3)	1622 (13.2)	1488 (14.0)	7426 (69.7)	1736 (16.3)	3075 (29.0)	3281 (31.0)	3204 (30.2)	1041 (9.8)
Unknown	182 (28.1)	315 (48.6)	93 (14.4)	58 (9.0)	139 (13.6)	723 (70.8)	159 (15.6)	100 (23.4)	142 (33.2)	119 (27.8)	67 (15.7)
General health											
Poor	62 (11.2)	215 (38.7)	136 (24.5)	142 (25.6)	67 (12.7)	333 (63.1)	128 (24.2)	109 (41.9)	70 (26.9)	50 (19.2)	31 (11.9)
Not so good	1715 (17.5)	5012 (51.1)	1757 (17.9)	1329 (13.5)	1208 (12.4)	6663 (68.6)	1849 (19.0)	2083 (31.1)	2102 (31.4)	1773 (26.5)	737 (11.0)
Good	5257 (20.8)	12154 (48.1)	4591 (18.2)	3247 (12.9)	3662 (16.3)	16103 (71.5)	2747 (12.2)	6999 (31.6)	6971 (31.5)	6049 (27.3)	2143 (9.7)
Very good	1601 (21.8)	3165 (43.2)	1557 (21.2)	1011 (13.8)	1515 (24.6)	4222 (68.6)	418 (6.8)	2567 (36.7)	2233 (31.9)	1618 (23.1)	578 (8.3)
Unknown	193 (23.3)	423 (51.1)	130 (15.7)	82 (9.9)	187 (16.4)	791 (69.2)	165 (14.4)	188 (26.7)	248 (35.2)	189 (26.9)	79 (11.2)
Cardiometabolic disease status‡											
Healthy	7338 (20.8)	16736 (47.5)	6540 (18.6)	4632 (13.1)	5498 (17.6)	22065 (70.6)	3691 (11.8)	9989 (31.8)	9951 (31.7)	8426 (26.9)	3003 (9.6)
CMD	1218 (17.4)	3495 (49.8)	1334 (19.0)	971 (13.8)	918 (12.7)	4948 (68.7)	1341 (18.6)	1588 (35.9)	1344 (30.4)	1015 (23.0)	473 (10.7)

*Highest level of education: basic upper secondary school or less (primary school to upper secondary education at the 12th class level, folk high school); advanced upper secondary (secondary education at 13th class level, other post-secondary non-tertiary education like vocational school); tertiary (education at the 14th class level or higher; undergraduate, graduate, postgraduate levels).

†Meeting Norwegian physical activity guidelines of at least 30 min of physical activity daily at work or in leisure time; no unknown category because the cell size was too small (n=63).

‡Cardiometabolic disease (CMD) status: Healthy participants are those without CMD or cancer; CMD denotes participants with CMD.

BMI, body mass index.

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higher in men, younger age groups, participants with unknown BMI, tertiary education, insufficient physical activity (did not meet physical activity guidelines) and poor self-rated general health. TV-viewing duration tended to be higher in participants aged 60 years or older, those with unknown BMI, lower or unknown education levels, poor self-rated general health and those with CMD. Participants reporting mostly sitting at work tended to be male, educated at the tertiary level, be insufficiently active (did not meet physical activity guidelines) and have poor self-rated general health.

During a mean 3.3 years of follow-up, a total of 1068 deaths occurred, of which 388 were related to CMD. Table 2 presents adjusted models showing associations between sedentary behaviours and mortality for the total HUNT3 sample (137 315.8 person-years). Relative to those with <4 h/day of total sitting time, participants with ≥ 10 h/day total sitting time had a 65% and 115% greater risk of all-cause and CMD-related mortality, respectively, after adjustment for sex, education, BMI, physical activity, smoking, self-rated general health and CMD status. Although we observed no difference in risk of all-cause or CMD-related mortality relative to the reference group among participants who reported total sitting times of 4–<7 and 7–<10 h/day, the trend of increased risk of mortality with higher sitting time was highly significant for both all cause (HR=1.17, $p=0.001$) and CMD (HR=1.29, $p=0.001$) mortality.

Participants with higher levels of TV-viewing time (1–3 and ≥ 4 h/day) did not differ in mortality risk from all causes or from CMD compared with those with <1 h/day of TV-viewing (table 2). Participants with jobs requiring much walking and lifting had 35% lower risk of all-cause mortality than those with jobs requiring mostly sitting (table 2). However, there was no difference in risk of mortality from all causes or from CMD when participants with jobs involving mostly sitting were compared with those with jobs that required more physical activity. Tests for trend across job type were also not significant for both outcomes (table 2).

We checked for the potential confounding of effects due to unknown pre-existing illness at baseline by repeating the analyses excluding participants with less than 1 year of follow-up (489 deaths, $n=41\,926$), but the results were unchanged. For example, after excluding those with less than 1 year of follow-up time, the all-cause mortality HRs for total sitting times of 4–<7, 7–<10 and ≥ 10 h/day were 1.07 (95% CI 0.82 to 1.40), 1.17 (95% CI 0.86 to 1.61) and 1.63 (95% CI 1.17 to 2.26), respectively, compared with the reference category of <4 h/day. We also examined the data for participants free of CMD at baseline ('healthy', $n=35\,107$) and the analyses yielded the same pattern of results although CIs were wide due to the small number of deaths ($n=296$ for all-cause; $n=84$ for CMD-related; data not shown).

An additional analysis (data not shown) was carried out on the HUNT2 data collected earlier in 1995–1997. The occupational sitting/activity measure was identical to that used in HUNT3 and we found that out of 45 685 respondents, 3837 deaths occurred after 12–14 years follow-up. Compared with participants with jobs requiring mostly sitting, those with jobs requiring much walking, much walking and lifting and heavy physical labour had HRs for all-cause mortality of 0.89 (95% CI 0.82 to 0.96), 0.82 (95% CI 0.74 to 0.91) and 0.82 (95% CI 0.74 to 0.91), respectively, after adjusting for sex, age, education, physical activity, smoking, BMI, CMD status and self-rated general health (p -trend < 0.001). Relative to participants with mostly sitting jobs, the HRs for CMD-related mortality associated with jobs requiring much walking, much walking and lifting and heavy physical labour were 0.80 (95% CI 0.71 to 0.91), 0.72 (95% CI 0.61 to 0.86) and 0.76 (95% CI 0.64 to 0.89), respectively, after adjusting for covariates (p -trend < 0.001).

DISCUSSION

The results of this study suggest that higher levels of total sitting time are associated with significantly higher risk of all-cause and CMD-related mortality in adults from the HUNT3 cohort

Table 2 Associations between sedentary behaviours and mortality from all causes and cardiometabolic diseases for the total sample (adjusted HRs and 95% CIs), HUNT3

	All cause mortality			CMD-related mortality		
	HR	95% CI	p-Trend	HR	95% CI	p-Trend
Total sitting time (h/day) ($n=42077$)*						
Number of deaths	640			236		
<4	94	1.00		33		
4–<7	302	1.12	0.89 to 1.42	102	1.07	0.72 to 1.60
7–<10	122	1.18	0.90 to 1.57	46	1.15	0.72 to 1.84
≥ 10	122	1.65	1.24 to 2.21	55	2.15	1.34 to 3.44
			0.001			0.001
TV-viewing time (h/day) ($n=38401$)*						
Number of deaths	684			267		
<1	66	1.00		26	1.00	
1–3	455	0.98	0.75 to 1.27	175	0.91	0.60 to 1.40
≥ 4	163	1.11	0.83 to 1.48	66	1.08	0.68 to 1.72
			0.312			0.493
Occupational ($n=45685$)*						
Number of deaths	244			81		
Mostly sitting	93	1.00		30		
Much walking	61	0.73	0.51 to 1.03	14	0.62	0.31 to 1.24
Much walk and lift	44	0.65	0.44 to 0.97	14	0.77	0.37 to 1.59
Heavy labour	46	0.95	0.64 to 1.40	23	1.55	0.83 to 2.90
			0.441			0.185

*Model adjusted for sex, body mass index, education level, meeting PA guidelines, smoking status, general health status, cardiometabolic disease (CMD) status with age as the time axis. Person-years: 137 315.79 (total sitting), 125 772.35 (TV-viewing) and 116 713.7 (occupational sitting).

followed for 3.3 years. In contrast, TV-viewing time and occupational sitting showed no or borderline significant associations with all-cause or CMD-related mortality over the same follow-up period in HUNT3 participants. However, the analysis of the HUNT2 occupational sitting data found higher mortality risk for participants who mostly sat at work relative to those in more active occupations over a longer follow-up period.

Our finding that adults reporting ≥ 10 h/day of total sitting time had a 65% higher risk of all-cause mortality than those with < 4 h/day is consistent with the findings reported in the few previous prospective studies. For example, Australian men and women aged 45 years and older with a total sitting time of 8–11 or > 11 h/day had 15% and 40% higher risk, respectively, of all-cause mortality relative to people with < 4 h/day of total sitting time.¹³ Comparable effect sizes have been found among American⁵ and Canadian adults¹⁰ suggesting that there is a dose–response relationship between higher amounts of total sitting time and risk of mortality.

Converse to other research, this study found no significant associations between TV-viewing time or occupational sitting and mortality. Several population cohort studies have reported that higher durations of TV-viewing and/or other screen-based activities were associated with an increased risk of all-cause mortality.^{5 6 8 22} While a recent meta analysis reported that the risk of all-cause mortality increased by 13% for every 2 h of TV-viewing,²³ the small number of studies included ($n=3$) highlights the need for more studies to confirm the longitudinal evidence that higher amounts of TV-viewing increase the risk of all-cause mortality. One potential reason for the different results observed in this study could be the suboptimal measure of TV-viewing used in HUNT3 resulting in 70% of respondents reporting TV-viewing in the middle 1–3 h/day category.

Similarly, the evidence base regarding occupational sitting and all-cause mortality is small. A recent systematic review of occupational sitting and health risks reported that in four of six prospective studies reviewed, occupational sitting was associated with greater risk of all-cause mortality, one study found no association, while one study found that sitting at work was associated with lower mortality risk.¹² The results of the current study showed a trend towards HUNT3, and further evidence of HUNT2 increased mortality risk with more sedentary occupations.

One possible explanation for the different pattern of results observed for total sitting time, TV-viewing and occupational sitting with mortality risk in the HUNT3 data may be that total sitting time, consisting of sitting in different domains and contexts over a day (eg, TV-viewing and sitting at work) has a cumulative effect on health, that is, evident in the short term (3.3 years in this study), while the effects of sitting in individual domains and contexts are less obvious in the same timeframe. We found some support for this hypothesis from a subanalysis involving the HUNT2 cohort which found a clear risk for occupational sitting and mortality relative to the more active occupational categories, but over a longer follow-up (12–14 years). Further, studies of total sitting time as the exposure variable have follow-up periods ranging from 2.8 to 12 years^{5 10 13 14} and have consistently found that higher levels of total sitting are associated with an increased risk of all-cause mortality. Prospective studies finding adverse associations between TV-viewing and all-cause mortality risk have followed participants for between 6.6 and 9.5 years^{5 6 22} and studies of occupational sitting finding greater all-cause mortality risk with sedentary occupation had a follow-up of 6–20 years.^{24–27} However, studies which reported no or opposite associations

between sitting at work and all-cause mortality did also have mean follow-up times of 8–12 years.^{28 29}

Another possibility is that domain-specific sedentary behaviours, such as TV-viewing, have shown greater measurement reliability than global measures of sedentary behaviour, like total sitting time.³⁰ Other studies have also found that single-item measures of global sitting produce lower estimates than measures consisting of domain-specific questions.^{30 31} We could not determine the extent to which differences in reliability of the various sedentary behaviour measures in HUNT3 may have affected the findings; although, it is possible that total sitting time in the HUNT3 cohort was underestimated, which suggests that the estimates observed in this study are likely to be conservative.

To the best of our knowledge, this is the first study to examine the associations between sedentary behaviour and mortality related to cardiometabolic illness. We included cause-specific analyses of death from diabetes and related metabolic diseases because the literature suggests that sedentary behaviour has a direct effect on metabolic and vascular health.³² Studies have demonstrated that sedentary behaviour disrupts vascular and metabolic function because the inactivity in skeletal and postural muscles that results from prolonged sitting leads to changes in lipoprotein lipase activity which in turn elevate plasma triglyceride levels, reduce high-density lipoprotein cholesterol levels and decrease insulin sensitivity.^{32 33}

Previous studies examining sedentary behaviour and CVD-related mortality have reported that higher levels of total sitting time,^{5 10} TV-viewing^{5 6} and occupational sitting^{24 25 27} are associated with higher risk of CVD-related mortality, although others have also found no associations with TV-viewing¹¹ or occupational sitting.^{28 29} In this study, we found that the risk of death from CMD in HUNT3 participants associated with total sitting time per day was 115% higher in people sitting ≥ 10 h/day relative to those sitting < 4 h/day, but no association with the levels of TV-viewing and occupational sitting. It is possible that the risk of mortality related to CVD and metabolic diseases associated with sedentary behaviour may differ; however, we were unable to conduct separate analyses due to the small number of deaths attributed to these causes.

Strengths and limitations

The strengths of this study are that it involved a large population cohort and identified deaths through the linkage of the HUNT survey with the Norwegian Causes of Death Registry. The analyses also took into account many confounders, including age, education level, BMI, smoking, physical activity, existing CMD and self-rated general health, although residual confounding from other known or unknown confounders is possible. Furthermore, this is one of few studies to examine the risk of mortality associated with multiple contexts of sedentary behaviour.

One limitation of this study is the relatively short follow-up period (3.3 years), which may have led to residual confounding effects due to unknown pre-existing illness at baseline; however, the results were largely unchanged after the exclusion of participants who died in the first year of follow-up. Using self-report measures for the sedentary behaviour, exposure variables may have introduced measurement error although similar measures of total sitting, TV-viewing time and occupational sitting used in other population cohort studies have shown adequate reliability and validity. Information on lifetime exposure was not available as total sitting and TV-viewing were only assessed once and could have varied over time. Also, the study population came

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from a semirural region of Norway and it is possible that their patterns of sedentary behaviour (eg, TV-viewing) and physical activity may have differed to those of more urban populations and affected the results of this study.

In conclusion, this study adds to the increasing evidence base that sedentary behaviour is a risk factor for premature mortality. While extended periods of sitting time in specific contexts (ie, watching TV and at work) do not seem to be associated with all-cause or CMD-related mortality in the short-term (around 3 years), total sitting time accumulated on a daily basis appears to have a deleterious impact on health in the same timeframe. Given the high prevalence of total sitting time in adults in developing and developed countries (346 ± 204 min/day),³⁴ these findings have important public health implications. At the very least, these data support current recommendations that adults should be encouraged to sit less throughout the day to reduce their daily total time spent sitting.^{35 36}

What are the new findings?

- ▶ Total sitting time accumulated on a daily basis appears to be associated with mortality due to all causes or cardiometabolic diseases (CMD) in the short term (around 3 years); however, prolonged sitting in specific contexts (ie, watching TV and at work) do not seem to adversely impact health in the same timeframe.
- ▶ This study found that adults sitting for ≥ 10 h/day in total had a 65% and 115% greater risk of all-cause and CMD-related mortality, relative to those with < 4 h/day of total sitting time in models that adjusted for multiple potential confounders including physical activity.
- ▶ There were no significant associations between TV-viewing time or occupational sitting and mortality related to all causes and CMD in adjusted models.

How might it impact on clinical practice in the near future?

- ▶ This study found that higher total sitting time each day is associated with a greater risk of premature death from all causes and CMD, after taking physical activity into account, consistent with the findings from other international cohort studies.
- ▶ While current guidelines do not make specific recommendations for sitting reduction, it may be time for clinicians to start thinking broadly about 'active living' (moving more and sitting less) as part of preventive practice.
- ▶ Clinical practice could encourage adults to sit less throughout the day to reduce their daily total sitting time.

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Contributors JYC, HPVDP and AEB conceptualised the study and research questions. JYC, HPVDP, AEB and KM applied for study data access from the Norwegian Data Inspectorate and Regional Committee for Medical and Health Research Ethics in Mid-Norway. JYC managed the study from Australia;

KM coordinated the study from Norway and organised applications for data access and ethics approval. KM, TLH and JH provided expertise regarding the HUNT Study. JYC planned the statistical analyses and interpreted the data with input from all coauthors. AG analysed the data. JYC, AG and AEB drafted the manuscript and all coauthors critically revised the manuscript for intellectual content. All authors read and approved the final manuscript.

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